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Orbital Radio Relays

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While orbital radio relays probably could not compete with microwave radio relay for communication over land, they might be useful in transoceanic communication. Three sorts of repeaters appear to be consistent with microwave art: (a) 100-ft reflecting spheres at an altitude of around 2200 miles; (b) a 100-ft oriented plane mirror in a 24-hr orbit, at an altitude of 22,000 miles; (c) an active repeater in a 24-hr orbit. Cases (a) and (b) require at 10-cm wavelength 250-ft-diam antennas and 100-kw and 50-kw power, respectively; in case (c), using 250-ft antennas on the ground and 10-ft antennas on the repeater, only 100 watts on the ground and 0.03 watt on the repeater would be required; in this case one should probably use smaller antennas on the ground. In cases (b) and (c) the problem of maintaining the correct orientation and position of the repeater is critical; perturbations by the moon and sun might cause the satellite to rock or wander prohibitively.

Introduction

FOLLOWING the announcement last year that the American Telephone and Telegraph Company and the British Post Office have jointly undertaken the construction of a 36-channel two-way submarine telephone cable across the Atlantic at a cost of 35 million dollars, it is natural, at least for a person who is a complete amateur in such matters, to speculate about further developments in transoceanic communication, even into the far future.

Would a channel 30 times as wide, which would accommodate 1080 phone conversations or one television signal, be worth 30 × 35 million dollars; that is, a billion dollars? Will someone spend this much trying to make a broad-band channel to Europe? The idea is of course absurd. At the present, there is no commercial demand which would justify such a channel. By the time there is, surely some technical solution to the problem will be sought which does not involve multiplying the cost of the present cable in proportion to the bandwidth.

It is conceivable that such a solution could come about through further development in the field of cables, but a very difficult step must be taken to multiply the channel capacity by 30 or more. In the meantime, other means for obtaining a broad-band channel to Europe have been considered, including routes largely across land rather than across water.

A route from Labrador or Baffin Island to Greenland, around the coast of Greenland, thence to Iceland and via the Faroe Islands to Scotland traverses much nasty country by land and still leaves gaps of several hundred miles by sea. These gaps might conceivably be spanned by radio, using very high power. Perhaps it may be possible to make undersea television cables which would span gaps of a few hundred miles before such cables can be made to span thousands of miles. Even granting the success of a difficult radio link or a broad-band cable, both terrain and climate make this indirect route difficult and unappealing.

A route from Alaska across the Bering Strait to Siberia, and thence overland to Europe is conceivable, but it is difficult and indirect and it has other disadvantages which need not be mentioned.

Radio relay along a continual chain of planes crossing the Atlantic has been proposed. While this is certainly technically feasible, in good weather at least, it seems strange either as a long-range or a short-range solution.

Another "solution" has been proposed to the problem of transoceanic communication; that is, relaying by means of a satellite revolving about the earth above the atmosphere. Many engineers do not doubt that it will eventually be possible to put a satellite up and into place, nor to supply it with small amounts of power for long periods and to exercise some sort of radio control over it. However, there is no unclassified information in regard to how long it will be before a satellite could be put up or what it might cost to do so, and there may not even be classified information on the subject. Thus, although some aspects of transoceanic communication via a satellite are being considered in this paper, nothing can be said at this point about the over-all feasibility of such communication, which must depend on the feasibility of the satellite itself.

Fortunately, there is a good deal else to be said about the matter. For instance, only *transoceanic* communication has been mentioned, and for a reason. There are at present transcontinental television circuits. The announced cost of the American Telephone and Telegraph Company's transcontinental TD2 microwave system was 40 million dollars. This is only 5 million dollars more than the 35 million for the 36-channel transatlantic cable, and yet the TD2 system provides a number of television channels in both directions, as well as many telephone channels. Perhaps even more important in an overland system, it provides facilities for dropping and adding channels along the route. Without such flexibility, an overland system would be almost useless.

Some types of satellite relay systems would provide communication only between selected points. These would lack the flexibility required for overland service. Further, there is little reason to believe that a satellite relay could compete with present microwave radio relay or coaxial cable in cost. Present facilities are very satisfactory, so that there is little incentive to replace them with some difficult alternative sys-

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tem, even if it could do the same job. Thus, satellite radio relay seems attractive only for spanning oceans.

Two different sorts of satellite radio repeaters suggest themselves. One consists of enough spheres in relatively near orbits so that one of them is always in sight at the transmitting and receiving locations. This sphere isotropically scatters the transmitted signal, so one has merely to point the transmitter and receiver antennas at it to complete the path. Another system uses a plane mirror or an active repeater with a 24-hr orbital period, located directly above the equator at a radius of around 26,000 miles or an altitude of about 22,000 miles. Such a satellite would be visible to within 9 deg of the poles; that is, in all inhabited latitudes. If it were not for the perturbations of the orbit by the moon and the sun, it could stay fixed relative to the surface of the earth, and large fixed antennas could be used on earth. However, it appears that perturbation of the orbit would be large enough to necessitate steerable antennas on earth and orientation of the satellite antennas or the reflector by remote control.

Even disregarding problems concerned with the making and placing of the satellites, would such satellite relay systems or any satellite relay system be feasible in other respects? To decide this, two sorts of problems must be considered: problems of microwave communication, and problems lying in the field of celestial mechanics, concerned with the orbit and orientation of a satellite. First to be examined are some of the problems of microwave communication.

Problems of Microwave Communication

Allowable path loss is a dominating consideration in a satellite radio relay system, and the allowable path loss depends on the system of modulation used. Systems of modulation such as binary pulse code modulation, which require small power but large bandwidth, seem particularly suitable. Consider, for instance, an 8-digit binary p-c-m system with a sampling rate of 10 mc and a limiting bandwidth of 5 mc. Such a system allows a ratio of r-m-s quantizing noise to peak-to-peak signal of about 59 db, or a ratio of the power of the maximum-amplitude sine wave which can be transmitted to r-m-s noise of about 50 db. If double-sideband pulses are to be used in connection with such a system, the ideal minimum bandwidth is 40 mc, and an r-f signal-to-noise ratio of around 20 db will be needed if errors are to be kept very infrequent.

Using a 40 r-f band and a 5-mc video band in transmitting high-index f-m would give an f-m gain of about 12 db; adding this to the 20 db r-f noise figure would give an over-all noise figure of around 32 db, which is somewhat worse than that for 8-digit p-c-m. Thus, the following calculations will be based on 8-digit p-c-m.

Further, an r-f receiver noise figure of 6 db will be assumed. This noise figure has been attained in a traveling-wave tube at a wavelength of 10 cm. It may be noted that thermal noise at 20 C (used as a reference in specifying noise figure) is −204 db (db with respect to one watt) for 1 cps bandwidth.

Figures concerning this reference system and the received power required are shown in Table 1.

Table 1

Modulation	8 digit binary p-c-m
Video bandwidth	5 mc
r-f bandwidth	40 mc
r-f signal-to-noise	20 db
r-f noise figure	6 db
r-f received signal	−102 dbw

This figure of −102 dbw may be somewhat optimistic because we have assumed the ideal minimum r-f bandwidth. On the other hand, great care in minimizing the bandwidth would be justified.

Using the power given in Table 1, the allowable path loss vs. transmitter power can now be tabulated, as in Table 2.

Table 2

Transmitter power, watts	Allowable path loss, db
0.01	82
0.1	92
1	102
10	112
100	122
1,000	132
10,000	142
100,000	152
1,000,000	162
10,000,000	172

Matters which govern path loss now need to be explored. In terrestrial microwave systems, fading and atmospheric attenuation are important. In satellite relay communication, no allowance for fading or atmospheric absorption should be necessary. The total mass of the atmosphere, looking through it vertically, is equivalent to about 5 miles of air at sea level. The stratifications which cause changes in path angle, and, hence, fading in long horizontal paths are presumably horizontal and will not much affect transmission near to the vertical. There cannot be a long path through rain when we look up at a steep angle. Thus, all the considerations will be based on free-space transmission.

First the matter of antenna directivity will be considered. For an antenna with a width w and operated at a wave length λ, the beam width in radians, θ, is roughly

$$\theta = \frac{\lambda}{w} \qquad [2.1]$$

By using this relation, the beam width in miles at a range of 22,000 miles was calculated for several wavelengths and antenna diameters. This information, together with the approximate angular width of the beam in degrees, is given in Table 3. From Table 3, two difficulties can immediately be

Table 3

Wavelength, cm	Beam width, miles (approx. angular beam width, deg) for antenna diam., ft		
	1000	100	10
1	0.72 (0.0019)	7.2 (0.019)	72 (0.19)
3	2.2 (0.0056)	22 (0.056)	220 (0.56)
10	7.2 (0.018)	72 (0.19)	720 (1.9)

noted: It is impractical to have a receiving antenna large enough to intercept more than a small fraction of the transmitter power. If large antennas are used, they must be directed very precisely.

If the antenna were to be directed at an essentially fixed object, such as a 24-hr satellite with an orbit unperturbed by sun or moon, then the use of very large fixed antennas built into the earth, steerable over very small angles by moving the feed might be considered. It seems likely that perturbations of the orbit of a "fixed" satellite will be so large as to necessitate a fully steerable antenna. The Jodrell Banks antenna for radio astronomy will have a diameter of 250 ft. It seems reasonable that satisfactory 250-ft antennas could be made for costs compatible with the over-all cost of a satellite project, and henceforward 250 ft will be taken as a maximum antenna diameter. It would, however, be hard to support this as either a maximum or a minimum size.

The path loss depends on other matters than antenna size; it depends on the general sort of repeater that is used. There

are two main types of repeaters: active repeaters, with powered transmitters and receivers, and passive repeaters, i.e., mere reflectors.

Passive Repeaters

Passive repeaters are very attractive in many ways. They would require no maintenance and they would be almost immune to meteor damage. It will be shown that some kinds might require remote control devices for orientation, but these could be simple.

Isotropic Reflectors

One type of passive repeater which will be considered is a sphere, which acts as an isotropic reflector and scatters the intercepted power equally in all directions. Such a repeater is of use between any two locations in sight of it.

If A_T is the area of a transmitting antenna and A_R is the area of a receiving antenna,[2] the ratio of power received to power transmitted, P_R/P_T, is

$$\frac{P_R}{P_T} = \frac{A_T A_R}{\lambda^2 d^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots [2.2]$$

Here λ is the wavelength and d is the distance between the transmitting antenna and the receiving antenna.

Suppose that the transmitting antenna has an area A_1 and the sphere which "receives" the power at a distance d a cross-sectional area A_2. Suppose that the sphere scatters the power uniformly over a solid angle of 4π radians and that the power finally received falls on an antenna of one A_1 at a distance d. Then the over-all ratio of power received to power transmitted $(P_R/P_T)_2$ is

$$\left.\begin{aligned}\left(\frac{P_R}{P_T}\right)_2 &= \left(\frac{A_1 A_2}{\lambda^2 d^2}\right)\left(\frac{A_1}{4\pi d^2}\right)\\ \left(\frac{P_R}{P_T}\right)_2 &= \frac{A_1^2 A_2}{4\pi\lambda^2 d^4}\end{aligned}\right\} \quad \ldots\ldots\ldots [2.3]$$

Circular transmitting and receiving antennas with diameters of 250 ft, a sphere with a diameter of 1000 ft, and a wavelength of 10 cm are considered. For a range of 22,000 miles the path loss will be 171 db. Referring to Table 2, it is seen that this would require a power of around 10 megawatts. Even allowing for the fact that a transmitter for binary p-c-m is on only half the time on the average, this seems a ridiculously high figure.

Going to a wavelength of 3 cm would cut the power requirement down by a factor of 10, but the power required still seems much too high.

The use of a number of spheres at some lower altitude might also be examined. There will certainly be a need to transmit over a total path length of thousands of miles. If, for example, a distance to the sphere of 2200 miles is taken, instead of 22,000 miles, then from Equation [2.3] is it seen that this would decrease the path loss by only 40 db, making the power requirement 1 kilowatt. However, a multiplicity of spheres is now needed, and perhaps a diameter of 1000 ft is unreasonable (even for one sphere, perhaps). Calling the diameter of the spheres to 100 ft would up the power by 20 db, calling for 100 kw at 10-cm wavelength.

A Plane Mirror

Suppose that a slightly concave mirror is used as a passive repeater. This could act as a perfectly focused transmitting and receiving antenna. If it is assumed, as it has been, that the transmitting antenna and the receiving antenna are equidistant from the mirror and 22,000 miles away from it, then the radius of curvature of the mirror should be 22,000 miles or 1.16×10^8 ft. If the diameter were 1000 ft, the concavity or depth of the mirror would be 2.16×10^{-4} ft or 2.5 mils. As this is small compared with the wavelength, the mirror can just as well be flat. Thus, it could act as a relay from any point in sight of its surface to a particular corresponding point.

Let A_2 be the area of the mirror. To get the over-all power ratio (P_R/P_T), Equation [2.2] is used twice: for going to the mirror, and back. We obtain

$$\left(\frac{P_R}{P_T}\right)_2 = \frac{A_1^2 A_2^2}{\lambda^4 d^4} \quad \ldots\ldots\ldots\ldots\ldots [2.4]$$

Again considering a 10-cm wave-length, 250-ft circular antenna and a 100-ft circular mirror, a path loss of $(P_R/P_T)_2 =$ 139 db is computed. According to Table 2, this would allow operation with a power of 50,000 watts.

In using a plane mirror there is a serious problem of satellite position and orientation. If the repeater moves x miles out of the position, the reflected beam moves $2x$ miles on the ground; if the repeater swings through an angle θ the reflected beam swings through an angle 2θ. From Equations [2.1] and [2.4] it is seen that changing the wavelength and the mirror diameter so as to keep the path loss constant does not affect the width of the returned beam. The requirements on orientation can be relaxed only by reducing the mirror diameter in wave lengths.

With a 100-ft mirror and a 10-cm wavelength, the beam is only 0.19 deg wide, which means that the mirror must be oriented to less than half of this angle, and the beam is only 72 miles wide at the surface of the earth.

A Corner Reflector

Suppose there is a corner reflector in a 22,000-mile equatorial orbit. Wherever this could be seen, it could be used to broadcast in the vicinity of the transmitter, for it will send what energy it receives back toward the transmitter. For zero wave length, radiation would fall over an area twice as great as that of the corner reflector. Actually, the area will be governed by the wavelength as well as by the size of the reflector as show in Table 2, and Equation [2.4] will apply.

It may be seen from Table 3 that, to get a reasonable coverage, only a rather small corner reflector can be used—say, 10-ft diam at a wavelength of 10 cm—and only a small receiving antenna, say, 4-ft-diam. Assuming transmitting antenna 250 ft in diam, the path loss turns out to about 211 db, which is much too high.

Active Repeaters

The big advantage of an active repeater is that the size and directivity can be relatively small. Thus, the orientation need not be as accurate as in the case of a plane reflector. It would seem desirable to make the repeater as small and as low-powered as possible, and hence one should perhaps use as large a receiving antenna on earth as seems reasonable. Thus, an antenna diameter of 250 ft will be assumed, as in the case of passive repeaters. A repeater antenna 10 ft in diam will be assumed. At a wavelength of 10 cm, the computed path loss computed by means of Equation [2.2] is 87 db.

Referring to Table 1, it is seen that this would require a transmitter power of only 0.03 watt or 30 milliwatts.

What about the link from earth to the satellite? Assume that a 250-ft transmitting antenna, a 10-ft receiving antenna, and transmitter power of 100 watts are used. Then the noise figure of the satellite receiver could be over 40 db, and the gain required would be only 52 db.

With these requirements, a single, low-voltage, low-performance traveling-wave tube should be quite adequate. Such a tube could be designed for very low cathode current density, and hence for long life. It could be operated by solar

[2] Neither here nor later is any distinction made between geometrical area and effective area of antennas. This will make a difference of a few db only, an amount negligible among other uncertainties.

batteries if some sort of storage could be provided. A 30-milliwatt traveling-wave tube, exclusive of power supplies could weigh 2 lb or less. Its power consumption, chiefly cathode power, could be 5 watts or less.

It may be noted from Table 3 that the orientation of the repeater could vary perhaps $\pm 1/2°$ and the location perhaps ± 200 miles.

3 Some Mechanical and Astronomical Problems

While no consideration will be given to the actual problem of getting a satellite into position, some consideration should be given to mechanical and astronomical problems before any comparison is made between the various systems discussed in the preceding section.

Weight

There now follows a very rough examination of what the weight of metallic spheres and mirrors might be.

Aluminum weighs 168.5 lb/ft^3. The area of a 100-ft circle is 7850 ft^2 and that of a 100-ft sphere is 4 times this. If the foil were 1 mil thick, the weight of the 100-ft mirror would be 110 lb and that of a 100-ft sphere would be 440 lb. The weight of a 1000-ft sphere would be 100 times as much, or 44,000 lb.

The mirror would have to be stretched on a frame which would weigh several hundred pounds.

To keep the sphere spherical, initially one could inflate it gently. Thereafter, loss of pressure because of meteor puncture would be expected. The spherical shape could be maintained either by straining the skin in the initial inflation, or by fastening to the sphere a beta emitter, so that the sphere would become positively charged and maintain its shape by means of electrostatic repulsion.

As opposed to the sphere, the mirror might be made out of mesh (e.g., tungsten mesh), with openings small compared with a wavelength.

Orbit

A sphere need only be put into the proper orbit. For a 24-hr orbit, intended to keep the sphere fixed in the sky, this would have to be done with considerable accuracy. An error of altitude of 1 ft would cause a drift out of position of 0.65 mile/year. If a drift of 10,000 miles (about 30 deg) in 50 years is allowed, the altitude would have to be accurate to about 300 ft. It is possible to measure the altitude much more accurately than this by means of radar, if only the astronomers can tell accurately what altitude the satellite should be put at.

There may, then, be envisioned an unmanned rocket maneuvered into position over a period of time by remote control guided by radar. Either the rocket could itself become the desired satellite by sprouting antennas or a reflector, or it could blow up a sphere and release it.

The subsequent orbit of the satellite is a problem for the astronomers. It would be very interesting to know how far about the sky a 24-ft "fixed" satellite would wander under the influence of the moon and the sun.

Orientation

A sphere need not be oriented in its orbit, but a satellite bearing a passive reflector or antennas would have to maintain a fixed orientation with respect to the surface of the earth.

It is not entirely out of the question to maintain such orientation automatically without expenditure of power. Consider a long beam revolving in an orbit. If it is in a radial orientation and is rotated slightly, there will be a restoring force tending to return it to radial orientation. The genesis of this force is easy to see. In the radial orientation the gravitational force on the outer portions is less than that on the inner portions, while the centrifugal force on the outer portions is greater than that on the inner portions. The beam is under tension. If the beam is rotated so as to bring the outer portions in, there is a couple acting against this rotation.

If the beam were forced to be normal to the radial direction there would be a couple tending to align it in the plane of the equator because the gravitation forces and the centrifugal forces do not act toward the same center. For a given angular displacement, this couple is less than that tending to align the beam radially.

A long, pointed equilateral triangle would tend to orient itself in the plane of the equator with the pointed end pointing radially in or out. More generally, of the principal axes of inertia, that about which the moment of inertia is greatest would tend to align itself parallel to the earth's axis, and that about which the moment of inertia is least would tend to align itself radially.

If the body were released in any different orientation it would oscillate forever about this preferred orientation unless damping were provided. The damping could be in the form of viscous liquid in a partly filled tube or container, or, preferably, unbalanced mechanical devices resonant at the frequencies of the natural oscillations of the body about its principal axes.

The natural period of oscillation can be calculated in a straightforward manner. For example, a simple body consisting of two equal masses connected with a rigid rod would tend to orient itself with the rod directed toward the center of the earth, and if slightly displaced in the equatorial plane it will oscillate with a period τ:

$$\tau = 2\pi \left(\frac{r_0}{3g_0}\right)^{1/2} \cdot \left(\frac{r}{r_0}\right)^{3/2} = 0.84 \left(\frac{r}{r_0}\right)^{3/2} \text{ hr}$$

where g_0 is the standard gravitational acceleration, r_0 is the radius of the earth, and r is the radial distance to the body. At 22,000 miles, the period would be 11 hr.

By fastening a mirror to a properly proportioned structure provided with damping, the mirror should automatically assume a fixed orientation with respect to the surface of the earth.

Perturbations by the moon both in the oribit and in the orientation of the repeaters would certainly rule out an automatic orientation. However, there might still be considered a remotely operated radio-controlled device which could correct orientation by shifting weights. Such a device could use transistors, very small motors, and perhaps solar batteries for power. The operation would be slow and intermittent. The control could be through very high-power pulsed signals, so as to call for a small low-directivity antenna on the satellite. The total power required might be less than for a relay receiver and transmitter.

4 Summary and Discussion

A number of problems in connection with satellite repeaters have been discussed in the previous sections. Endless variations and refinements could be made in assumptions. Perhaps frequency of operation and the antenna size should be considerably different from what has been assumed. However, the feasibility and cost of placing various sorts of satellites, which has not been, nor could be, discussed, would certainly strongly influence the nature and the size of satellite one might use.

Thus, the best that can be done is an attempt to state some sort of conclusions concerning the sorts of systems which have been described.

To aid in this discussion, some of the data arrived at earlier have been summarized in Table 4. All of these are for a 5-mc video channel provided by an 8-digit binary pulse code modulation system, as described in Table 1, and a wavelength

Table 4

Path length, miles	Repeater description	Power on earth	Repeater output	Orientation must be better than
22,000	1000-ft sphere	10 megawatts	0	No orientation
2,200	100-ft sphere	100 kw	0	No orientation
22,000	100-ft mirror	50 kw	0	±18 miles ±0.047 degree
22,000	10-ft antennas	100 watts	30 mw	±360 miles ±0.95 degree

of 10 cm. The diameter of the antennas on earth is assumed to be 250 ft.

The great advantages of the passive repeaters over active repeaters are potential channel capacity and flexibility. Once in place, passive repeaters could be used to provide an almost unlimited number of two-way channels between various points at various wavelengths. They would also allow for modifications and improvements in the ground equipment without changes in the repeater.

Spheres, which reflect isotropically, are the most flexible of passive repeaters, because they allow transmission between any two points in sight of them. Moreover, with spheres there is no problem of the angular orientation of the repeaters.

For a 24-hr "fixed" repeater and a 1000-ft sphere, the power required is 10 megawatts, and this seems excessive. However, suppose 10 spheres, each 100 ft in diameter, circled the earth above the equator at a fairly low altitude. At low latitudes, one or more would always be in sight. The path length would be only about a tenth that for the 24-hr orbit, and the power required would be around 100 kw, which seems quite feasible.

A plane mirror returns much more power than does a sphere of the same diameter. A 100-ft mirror at an altitude of 22,000 miles would call for a transmitter power of about 50 kw, which again is by no means unreasonable.

The great problem in connection with a plane mirror is that of position and orientation. If it were not for the perturbation caused by the moon and sun, the position and orientation of the mirror could be preserved automatically by a proper disposition of masses attached to the mirror and by the use of damping.

However, as perturbations of position and orientation will be too large to be tolerated, the orientation of the mirror would have to be adjusted by moving masses through radio control. The power required would be small, perhaps less than that required for an active repeater. The advantage of channel capacity would be preserved.

The plane mirror suffers a considerable limitation compared with the sphere, however. If it really hung fixed in the sky, it would provide communication between any point in sight of its face and another particular corresponding point. However, because perturbation by the sun and moon will cause it to wander about in the sky so that the orientation of the mirror must be adjusted to maintain a path between two particular points, a plane mirror can actually be used only to provide channels (and a large number of channels on different frequencies) between two particular points.

The disadvantage of passive repeaters is the great path loss, so that even assuming antennas of a difficult if not prohibitive diameter and accuracy, the power required is large, although probably attainable.

The attractive feature of an active repeater is the small power required and the small antennas needed at the repeater, as well as the small power required at the ground. Indeed, an actual design for an active repeater would probably call for smaller antennas on earth, perhaps for larger antennas on the statellite, and probably for higher powers on both earth and satellite. Because the antennas on the satellite would have a comparatively small directivity, and because for a given angular or positional shift the beam from a radiator shifts only half as far as the beam from a reflector, the orientation problem is considerably easier in the case of an active repeater than in the case of a plane reflector. However, there still is an orientation problem, in contrast to the case of a sphere used as a passive repeater.

The chief disadvantage of the active repeater, aside from disadvantages of power supply and life, is that it provides only the number and sort of channels that are built into it. Once it is in place, its channel capacity cannot be substantially increased by anything done on the ground, although some gain might be made by an increase in transmitter power and receiver sensitivity and by a modification of the nature of the signal.

In conclusion, it can be said that, disregarding the feasibility of constructing and placing satellites, it seems that it might be possible to achieve broad-band transoceanic communication using satellite repeaters with any one of three general types of repeater: spheres at low altitudes, or a plane reflector or an active repeater in a 24-hr orbit (at an altitude of around 22,000 miles).

At this point, some information from astronomers about orbits and from rocket men about constructing and placing satellites would be decidedly welcome.

Background

The basis for the microwave calculations in this paper will all be found in the references below (1–4). A fine over-all treatment of microwave repeaters is available (5). The reader may also be interested in the current status of the microwave tube art (6).

It is interesting to note that the problem of radio links to the planets has been treated by Richey as early as 1938 (7) and in considerable detail by J. J. Coupling in 1952 (8).

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